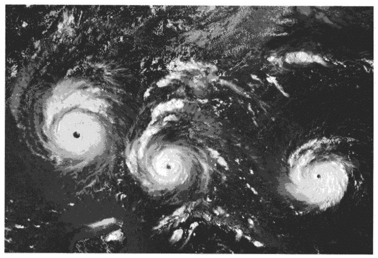
Lecture 7: Disturbance (Outline)



(From *Weather & Climate*)

- ❑ Transients and Eddies
- ❑ Climate Roles
- ❑ Mid-Latitude Cyclones
- ❑ Tropical Hurricanes
- ❑ Mid-Ocean Eddies

Transient and Eddy

❑ Transient: deviations from time mean

$$x' = x - \overline{x}$$ (Time Mean)

❑ Eddy: deviations from zonal mean

$$\overline{x}^* = \overline{x} - [\overline{x}]$$ (Zonal Mean)

❑ Why transients/eddies matter to zonal and time means?

$$[\overline{vT}] = [\overline{v}][\overline{T}] + [\overline{v}^*\overline{T}^*] + [\overline{v'T'}]$$

Flux Components

$$[\overline{vT}] = [\overline{v}][\overline{T}] + [\overline{v}^*\overline{T}^*] + [\overline{v'T'}]$$

(1) (2) (3)

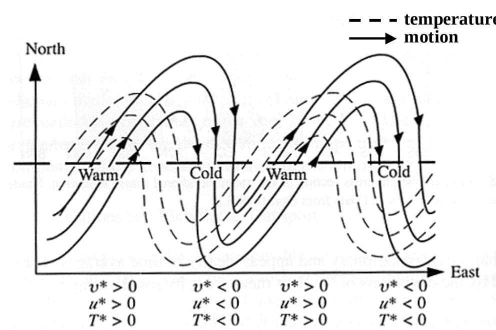
Three components contribute to the zonal- and time-mean transport:

(1) Mean Meridional Circulation (such as the three-cell circulation)

(2) Stationary planetary Waves (such as the wavenumber 1-3 eddies in the Northern Hemisphere).

(3) Transient Eddies (such as the weather systems = midlatitude cyclones and anticyclones).

Transient/Eddy Flux



[V*T*] > 0 ➔ On zonal average, eddies transport heat northward.
➔ Eddies contribute to zonal-mean heat transport

Climate Roles of Eddies

- Stationary and transient eddies are important to the poleward fluxes of temperature, moisture, energy, and angular momentum.

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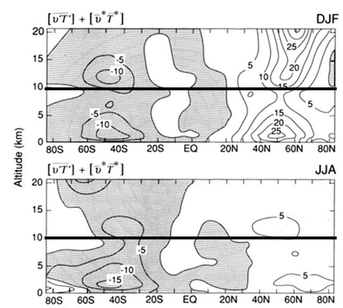
Poleward Flux of Temperature



(From *Global Physical Climatology*)

- Transient eddy fluxes dominant the meridional flux of temperature except in the Northern Hemisphere during winter, when stationary eddies contribute up to half of the flux.
- The low-level maximum in the troposphere is associated with the structure of growing mid-latitude cyclones (I.e., weather systems).

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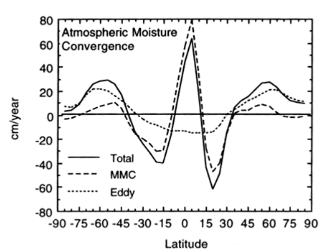
Poleward Flux of Moisture



(From *Global Physical Climatology*)

- Both the mean meridional circulation and eddies transport water and play an important role in determining the nature of the hydrological cycle.
- Moisture convergence in the tropics is dominated by the transport provided by the mean meridional circulation.
- The subtropcs serves as source regions for water vapor.
- Eddies remove water from the tropics and supply it to middle and high latitudes.

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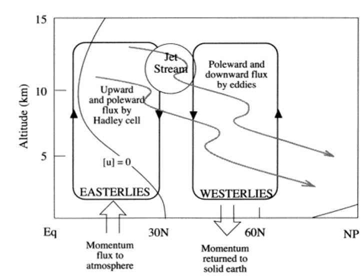
Poleward Flux of Momentum



- In the tropical easterlies, eastward angular momentum is transferred from Earth to the atmosphere via frictional forces and mountain torque.
- This westerly angular momentum is transported upward and then polarward into the Hadley Cell.
- Eddies then transport angular momentum polarward and downward into mid-latitude westerlies.
- In the mid-latitude, the westerly momentum is returned to the Earth.

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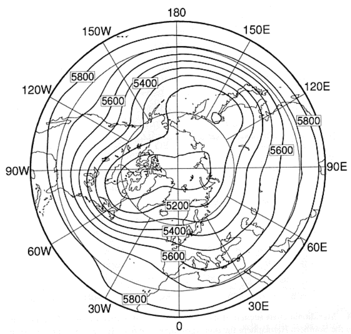
Stationary Planetary Waves

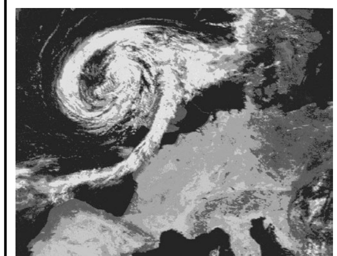
January Height of 500-mb Pressure Surface



(From *Global Physical Climatology*)

- ❑ Stationary: These waves do not move around much and are fixed in certain geographic locations.
- ❑ Planetary: These waves have large wavelengths, one the order of several thousands of kilometers.
- ❑ Wave: Their structures vary in the zonal direction.
- ❑ Stationary planetary waves are forced by large-scale mountains (such as Himalaya and Rocky mountain ranges) and heat contrasts between continents and oceans.
- ❑ Stationary planetary waves are stronger in winter than in summer.

Transient Eddies

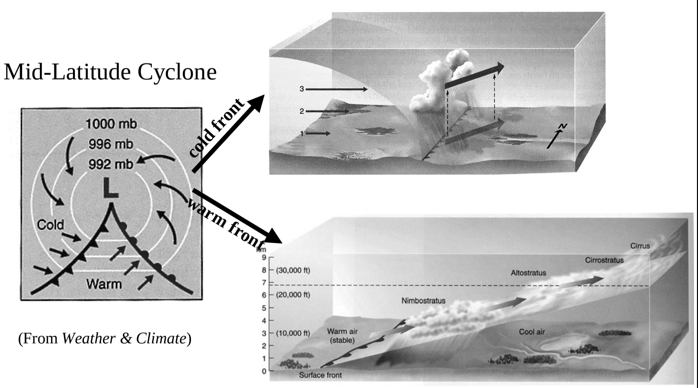


(From *Weather & Climate*)

- ❑ Mid-latitude cyclone and anticyclone are the major transient eddies that play an important role in meridional transports of heat, momentum, and moisture.
- ❑ These mid-latitude weather systems grow from the baroclinic instability associated with the strong north-south temperature gradients in mid-latitudes.
- ❑ Mid-latitude cyclones have typical spatial scales of wavenumbers 5-6 and have typical time scale of 7-10 days.
- ❑ Mid-latitude cyclones are marked by well-defined fronts separating the warm air mass from the south and the cold air mass from the north. (Very different from tropical hurricanes, which do not have frontal features).

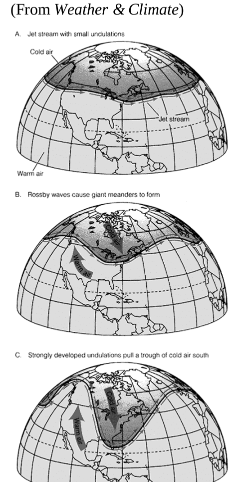
Cold and Warm Fronts

Mid-Latitude Cyclone



(From *Weather & Climate*)

(From *Weather & Climate*)



How Cyclone Grows?

Potential Energy ➔ Available P. Energy

(cold/warm air moves south/north)

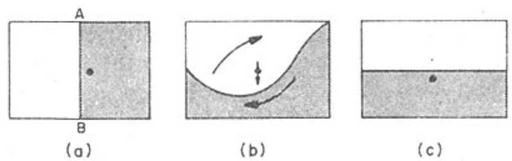
(V*T* > 0)

Available Energy ➔ Kinetic Energy

(cold/warm air moves down/up)

(W*T*>0)

Available Potential Energy



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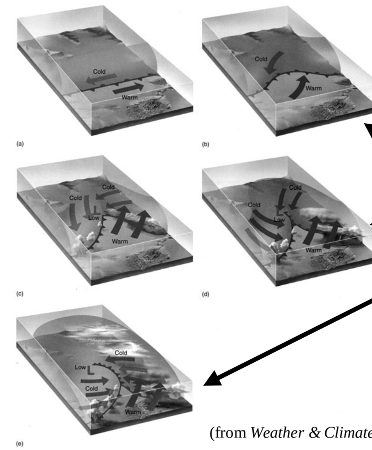
Life Cycle of Mid-Latitude Cyclone



- ❑ Cyclogenesis
- ❑ Mature Cyclone
- ❑ Occlusion

(from *Weather & Climate*)

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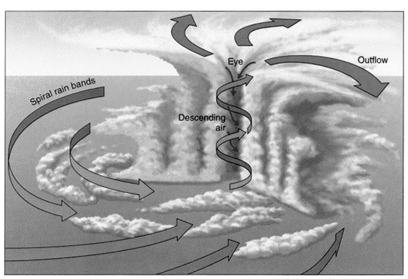
Tropical Hurricane



(from *Weather & Climate*)

- ❑ The hurricane is characterized by a strong thermally direct circulation with the rising of warm air near the center of the storm and the sinking of cooler air outside.
- ❑ The warm core of the hurricane serves as a reservoir of potential energy, which is continuously being converted into kinetic energy by the thermally direct circulation.

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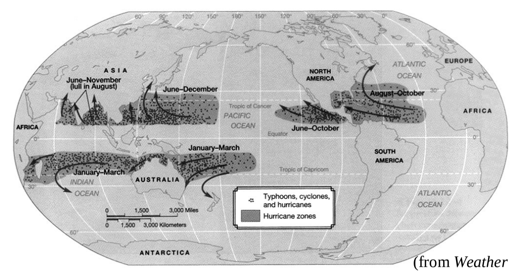
They Are the Same Things…



(from *Weather & Climate*)

- ❑ ***Hurricanes:*** extreme tropical storms over Atlantic and eastern Pacific Oceans.
- ❑ ***Typhoons:*** extreme tropical storms over western Pacific Ocean.
- ❑ ***Cyclones:*** extreme tropical storms over Indian Ocean and Australia.

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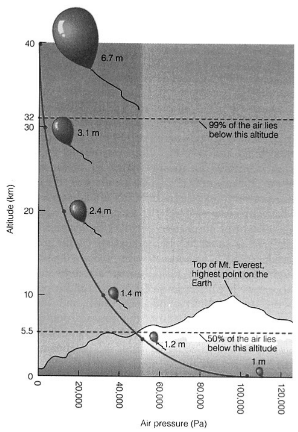
Air Parcel Expands As It Rises…



(from *The Blue Planet*)

- Air pressure decreases with elevation.
- If a helium balloon 1 m in diameter is released at sea level, it expands as it floats upward because of the pressure decrease. The balloon would be 6.7 m in diameter as a height of 40 km.

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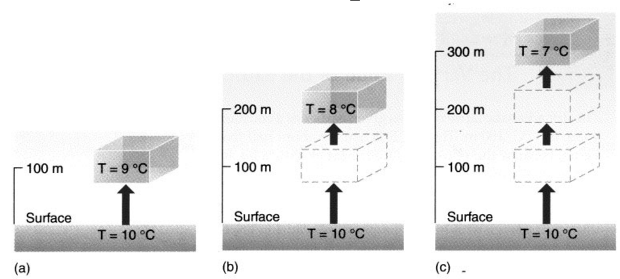
Adiabatic Lapse Rate



(from *Understanding Weather & Climate*)

- Adiabatic lapse rate
  = 10°C/km or 1°C/100m
  = air temperature in a rising balloon drops 1°C every 100m.

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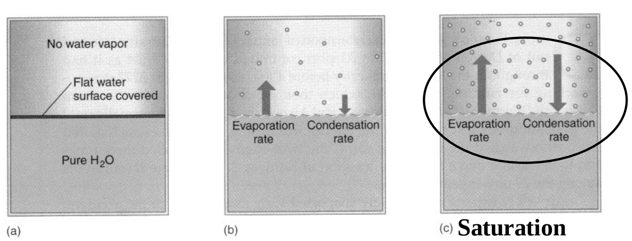
Water Vapor In the Air



Saturation

(from *Understanding Weather & Climate*)

- **Evaporation:** the process whereby molecules break free of the liquid volume.
- **Condensation:** water vapor molecules randomly collide with the water surface and bond with adjacent molecules.

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Specific .vs. Relative Humidity

specific humidity
6 gm/kg

saturated
specific humidity
10 gm/kg
→ Relative humidity
6/10 x 100%=60 %

saturated
specific humidity
20 gm/kg
→ Relative humidity
6/20 x 100%=30 %

- Specific Humidity: How many grams of water vapor in one kilogram of air (in unit of gm/kg).
- Relative Humidity: The percentage of current moisture content to the saturated moisture amount (in unit of %).
- Clouds form when the relative humidity reaches 100%.

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Why Clouds Form?

Clouds form when air rises and becomes saturated in response to adiabatic cooling.

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Cloud Type Based On Properties

❑ Four basic cloud categories:
- ✓ Cirrus --- thin, wispy cloud of ice.
- ✓ Stratus --- layered cloud
- ✓ Cumulus --- clouds having vertical development.
- ✓ Nimbus --- rain-producing cloud

❑ These basic cloud types can be combined to generate ***ten different cloud types***, such as cirrostratus clouds that have the characteristics of cirrus clouds and stratus clouds.

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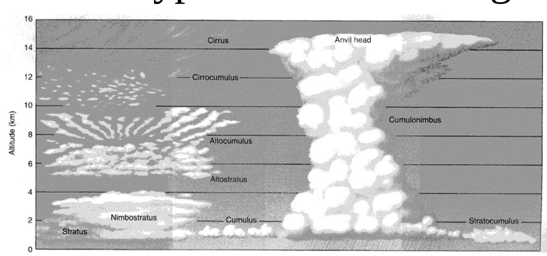
Cloud Types Based On Height



If based on cloud base height, the ten principal cloud types can then grouped into four cloud types:
- ✓ High clouds -- cirrus, cirrostratus, cirroscumulus.
- ✓ Middle clouds – altostratus and altocumulus
- ✓ Low clouds – stratus, stratocumulus, and nimbostartus
- ✓ Clouds with extensive vertical development – cumulus and cumulonimbus.

(from "*The Blue Planet*")

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Cloud Classifications

Table 12.1 Classification of Clouds in the Troposphere by Altitude

Height	Name	Shape and Appearance
High-level clouds		
Cloud base 6 to 15 km above sea level	Cirrus	Feathery streaks
	Cirrocumulus	Small ripples and delicate puffs
	Cirrostratus	Translucent to transparent sheet, like a veil across the sky
Middle-level clouds		
Cloud base 2 to 6 km above sea level	Altocumulus	White to dark gray puffs and elongate ripples
	Altostratus	Uniform white to gray sheet covering the sky
Low-level clouds		
Cloud base below 2 km above sea level	Stratus	Uniform dull gray cover over the sky
	Nimbostratus	Uniform gray cover, rain generally falling
	Stratocumulus	Patches of soft gray; in places patches coalescing to a layer
Clouds with great vertical development		
Cloud base below 3 km above sea level	Cumulus	Puffy cauliflower shape with flat base
	Cumulonimbus	Large, puffy; white, gray and black; great vertical extent, often with anvil-shaped head

(from "*The Blue Planet*")

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High Clouds

1. Cirrus Clouds

3. Cirrocumulus Clouds

(from Australian Weather Service)

2. Cirrostratus Clouds

- High clouds have low cloud temperature and low water content and consist most of ice crystal.

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Middle Clouds

4. Altostratus Clouds

5. Altocumulus Clouds

(from Australian Weather Service)

- Middle clouds are usually composite of liquid droplets.
- They block more sunlight to the surface than the high clouds.

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Low Clouds

6. Stratus Clouds

8. Nimbostratus Clouds

(from Australian Weather Service)

7. Stratocumulus Clouds

- Low, thick, layered clouds with large horizontal extends, which can exceed that of several states.

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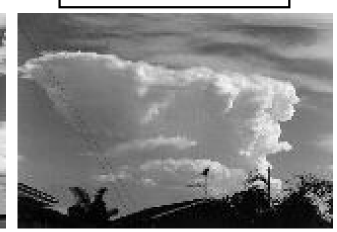
Clouds With Vertical Development

9. Cumulus Clouds

10. Cumulonimbus Clouds



(from Australian Weather Service)

- They are clouds with substantial vertical development and occur when the air is absolute or conditionally unstable.

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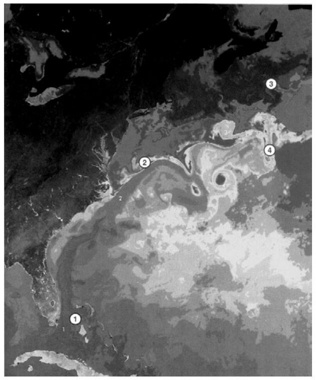
Mid-Ocean Eddies



(Figure from *Oceanography* by Tom Garrison)

- The Gulf Stream and the Kuroshio spin off long-lived eddies via baroclinic and barotropic instabilities.
- The role of eddies for heat transport in the ocean is likely much less than in the atmosphere.
- The oceanic eddies are best developed well poleward of the latitude of the maximum oceanic transport.
- The wind-driven and thermohaline circulations are likely to provide much more important contributions to the meridional heat flux in the subtropics.

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